

SPACE PHYSICS EDUCATIONAL OUTREACH SUPPLEMENT TO CONTRACT NO. NASW-4621

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PROJECT GOALS

The goal of this Space Physics Educational Outreach project was to develop a laboratory experiment and classroom lecture on earth's aurora for use in lower division college physics courses, with the particular aim of implementing the experiment and lecture at Saint Mary's College of California. The strategy is to teach physics in the context of an interesting natural phenomenon by investigating the physical principles that are important in earth's aurora, including motion of charged particles in electric and magnetic fields, particle collisions and chemical reactions, and atomic and molecular spectroscopy. As a by-product, the undergraduate students would develop an appreciation for naturally occurring space physics phenomena. The project was a collaborative effort of Dr. Richard A. Copeland, senior chemical physicist at SRI International, and Dr. C. Wesley Walter, assistant professor of physics at Saint Mary's College of California. A Saint Mary's College student, Marc E. Onishi, participated in the development and implementation of the project with support from a summer stipend provided by the project. An important aim of this project was to foster fruitful interaction between the individual investigators and also to establish connections between the participating institutions.

ACCOMPLISHMENTS

Most of the project goals have been accomplished during the past year. The laboratory experiment on earth's aurora was developed and implemented for the first time at Saint Mary's College. Dr. Walter has included a discussion of the aurora in his second-semester introductory physics course for the past two years, making use of both the audiovisual materials purchased with support of this project and his personal experience gained through working on this project. The audiovisual and demonstration materials on the aurora have also been used extensively in several lecture and lab courses. Specific highlights of the first year's effort were listed in last year's annual report. Highlights of the accomplishments of the second year include the following:

- 1) **Developed Advanced Physics Experiment.** A junior-level laboratory experiment to investigate optical emissions related to the aurora has been developed and used in the Advanced Physics Laboratory course, Physics 181. The apparatus used to simulate some aspects of the aurora is a microwave discharge cell with a flowing afterglow viewing chamber. The design of this apparatus was developed and tested in the first year of this project by student Marc Onishi working with Drs. Copeland and Walter at SRI during the summer of 1993. The discharge apparatus was constructed at Saint Mary's College by Mr. Onishi and Dr. Walter, with technical help from Dr. Copeland, during the January term 1995.

The laboratory experiment (see Appendix A) consists of first qualitatively observing the discharge and afterglow emissions as the pressure and composition of the gas (air and nitrogen) changes. The students are struck by the beauty of the nebulous flashes of green, violet, and orange light as the gas is changed. The afterglow spectrum is then recorded for several gas conditions using a computer-controlled scanning monochromator (purchased with funds primarily from this project). Features in the spectrum are then identified and the students are asked to interpret the data and come up with plausible explanations for the observed variations of the spectra with changes in gas composition and pressure.

The sequence of observations made by the students provides a nice framework for them to pursue open-ended and interesting explanations. As the fraction of oxygen in the primarily nitrogen discharge is increased, the observed afterglow spectrum first shows the disappearance of $N + N$ recombination features due to preemptive formation of NO, and then the broad NO₂ emission continuum due to association of the newly formed NO with O atoms. The students are led to discover and understand this progression with help from the instructor. Applications of this type of spectroscopic detective work to understanding planetary and solar atmospheres are also considered at this time.

A major difference between the spectrum of the aurora and the experiment afterglow is the lack of observation in the laboratory of the oxygen atom "green" and "red" lines that are so important in the aurora. The explanation of the present lack of observation of these features provides another challenging opportunity for the students to think critically about the experiment (see Appendix B).

The experiment has a great deal of pedagogical value, as it challenges students to interpret and explain observations when the results are not known ahead of time. This discovery process is much more like the activities of practicing scientists than the activities in the typical teaching laboratory in which the results are known, or at least anticipated, by the students before they even begin the experiment. Further, this experiment frames the laboratory investigations in the compelling phenomenon of earth's aurora, thus making a meaningful connection between classroom learning and the "real-world."

2) **Planned Introductory Physics Experiment.** Plans have been made for implementing an introductory-level version of the aurora lab in the second semester Introductory Physics Lab, Physics 4, during the fall semester of 1995. Following viewing of the video "The Aurora Explained," the students will do the following activities: a) qualitative observation of spectra emitted by various discharge lamps using diffraction gratings, b) qualitative demonstration of the microwave discharge apparatus, and c) measurements of the circular motion of electrons in a

magnetic field using a Bainbridge-type tube. All of these activities investigate the physical principles important in the aurora. Due to the lower-level nature of this introductory course, we think it is more appropriate to concentrate on only the qualitative aspects of the emission spectra as opposed to the detailed spectral measurements made in the advanced junior-level lab described above. However, the students are prepared at this point to understand the motion of charged particles in electric and magnetic fields. The measurements with the electron tube will be used to determine the charge-to-mass ratio of the electron.

3) Introduced Audiovisual Resources. Audiovisual materials purchased with funds from this project, including a video tape entitled "The Aurora Explained," have been used at Saint Mary's College in both of the introductory physics courses, Physics 11 (primarily for biology majors) and Physics 3 (for physics, engineering, and chemistry majors), and in the introductory astronomy course for non-science majors, Physics 90. The total number of students enrolled in these course at Saint Mary's College is approximately 130 students per year. The striking beauty of the aurora images in the video is quite compelling to the students, and leads them to a deeper appreciation for the physical principles at work in nature.

As a major aim of this project was to foster professional interactions among the participants, as well as institutional connections, it is particularly appropriate to discuss the scientific and personal development of the student researcher as a result of the project. The student participant, Marc Onishi, benefited greatly from the opportunity that this project gave him. During his work at SRI in the summer of 1993, he gained valuable experience with experimental apparatus and techniques, and was able to apply his classroom learning in an open-ended research setting. As a direct result of this initial research experience, Mr. Onishi participated the following summer in the NSF-sponsored Research Experiences for Undergraduates (REU) program at SRI, where he was supervised by Dr. Copeland doing laser spectroscopy and collisional energy transfer research. He interacted with a number of professional scientists at SRI International, and this led him to a fuller understanding of career opportunities in science. After graduating this spring from Saint Mary's College, Mr. Onishi hopes to go to graduate school to study atmospheric physics.

CONCLUSIONS AND FUTURE PLANS

The project has been a success at Saint Mary's College due to the substantial contributions of Dr. Copeland and other personnel and resources at SRI. The aurora lab will continue to be a part of the junior-level advanced lab course, and the materials will be used in lower-division labs in the future. Because of the somewhat specialized equipment necessary for the flowing discharge cell, in particular the microwave power supply, the apparatus to simulate

the aurora is not likely to be constructed at many undergraduate institutions. However, the "aurora in a bottle," which could easily be provided in undergraduate classes, generated a great deal of student interest and excitement on the Saint Mary's campus. This project has also provided the impetus to include discussions of auroras and atmospheric science in both introductory physics and astronomy courses at Saint Mary's College. In addition, Dr. Copeland will give a public lecture on atmospheric and space physics topics in the Brousseau Lecture Series at Saint Mary's College.

APPENDIX A

Advanced Physics Laboratory Experiment

EARTH'S AURORA

"Earth's aurora: it is one of the most magnificent and mysterious natural phenomena that can be viewed by man. This marvelous event occurs when protons and electrons emitted by the sun are caught in earth's magnetic field and they spiral down toward the earth along its magnetic field lines. Along the way they collide with atoms and molecules in earth's atmosphere.... after the electrons collide with oxygen and nitrogen [in the atmosphere], photons of light are emitted from the excitation and recombination of the atoms and molecules."¹ This, in a nutshell, is what causes the beautiful, shimmering, ghost-like aurora known as the "Northern Lights".

In this lab you will investigate some of the important aspects of earth's aurora. As an introduction, you will first watch a video² that describes the causes and effects of the aurora. Then you will investigate the optical spectrum of the light emitted by nitrogen and oxygen discharges using a laboratory apparatus that has been designed to simulate some aspects of the aurora. The emission spectra will be analyzed with the aim of understanding the excitation and emission of light from atoms and molecules that are important in the aurora.

BACKGROUND READING

A good introduction to earth's aurora is given in the attached article "The Aurora," S.I. Akasofu, *Scientific American*, December 1965 (pp. 55-62), which you should read before your lab meeting.

PROCEDURE

The laboratory apparatus that will be used to simulate the aurora is a low-pressure, flowing gas discharge cell. Energy is put into the gas by microwave power to excite and dissociate the molecules in the gas and to sustain the discharge. The gas pressure and mixture of gases (here, air and pure nitrogen) can be adjusted. The light is observed both in the area of the discharge itself and downstream from the discharge where the excited atoms and molecules form a "flowing afterglow." The characteristics of this afterglow are very dependent on the gas pressure and the molecules present, and can be made to simulate some aspects of the aurora.

You will first make qualitative observations of the afterglow as you vary the parameters of the discharge. Next you will measure the emission spectrum of the afterglow for two different discharges using the Digikrom 480 scanning monochromator coupled with the QuickLog computer data acquisition module. Then you will analyze the spectra and identify the origins of the major features.

For your write-up of this lab you should include the following:

1. Describe your qualitative observations of the discharge and afterglow when varying the parameters. Include descriptions of the colors and relative intensities, as well as other things you may notice.
2. Print out your experimental emission spectra as relative intensity vs. wavelength. Identify the species and states of as many of the features as you can, using the identified spectra of Reference 3 as a guide. Compare and contrast the spectra obtained by different lab groups. Try to come up with a plausible scheme of chemical reactions that can explain the progression of the observed spectra from the case of a pure nitrogen discharge to the case of an air discharge.
3. Among the most noticeable features in earth's aurora are the emission lines of atomic oxygen known as the "green line" (at 558 nm) and the "red line" (at 630 nm and 636 nm). These lines result from emission of oxygen atoms from excited metastable, long-lived states to lower states, as shown in the energy diagram below. Although these lines are very important in the aurora, they are not observed in your measured spectra of the microwave discharge. Discuss possible explanations for the lack of observation of the green and red lines in your spectra. (Hint: you might want to calculate the number of molecules per cm^3 at the pressure in the discharge cell to help your explanation.)

REFERENCES

1. M. E. Onishi, "Auroras: An Educational Experience," Summer Research Project Report (Unpublished, 1993). Project funded by NASA, June-August 1993.
2. "The Aurora Explained," video produced by The Aurora Color Television Project, Geophysical Institute, University of Alaska Fairbanks (1992).
3. A. Omholt, *The Optical Aurora*, Chapter 4 (Springer-Verlag, New York, 1971).

APPENDIX B

**Excerpt from Marc E. Onishi, "Auroras: An Educational Experience,"
Summer Research Project Report (unpublished, 1993).**

**Excerpt from Marc E. Onishi, "Auroras: An Educational Experience,"
Summer Research Project Report (unpublished, 1993).**

Earth's aurora: it is one of the most magnificent and mysterious natural phenomena that can be viewed by man. This marvelous event occurs when protons and electrons emitted by the sun are caught in the earth's magnetic field and they spiral down toward the earth along its magnetic field lines. Along the way they will collide with atoms and molecules in Earth's atmosphere. Since the protons are about 2000 times larger than the electrons, they are traveling slower than the electrons and are much more likely to transfer energy to atoms and molecules in the upper atmosphere. Since they do lose their energy more rapidly than the electrons, they are filtered out into the upper atmosphere. The electrons, being less massive and traveling at a higher rate of speed, are able to bounce off other atoms and molecules and are able to keep more of their kinetic energy, and thus make it further into the earth's atmosphere. At a height of 100 - 400 km above the earth the major molecular and atomic species are oxygen atoms and nitrogen molecules. After the electrons collide with the oxygen and nitrogen, photons are emitted from the excitation and recombination of the atoms and molecules. One of the aurora's most prominent features is its "green" line, which is the characteristic whitish-green tint of the most aurora, caused by the fluorescence of excited oxygen atoms ($O(^1S)$). The emitted photon of the $O(^1S)$ to $O(^1D)$ transition has a wavelength of 5577 angstroms, located in the middle of the visible spectrum.

The primary purpose of this experiment was to construct a laboratory apparatus that would be able to sustain a low-pressure (1-10 torr) gas discharge and to study the fluorescence of excited atoms and molecules in the discharge. The discharge contains the same gases in roughly the same proportions as the aurora, and thus should closely resemble the aurora itself. This discharge used was a microwave discharge cell, because of the similar internal systems. After the initial discharge, the gases are allowed to flow downstream where the metastable states of atoms and molecules are able to emit their photons. Evidence of activity similar to the aurora could be proven by taking a spectrograph of the discharge cell and looking for the atomic line at 5577 angstroms. However, when the spectrograph was taken, there was no evidence of the green line at all.

The first thing we did was to check and calibrate our instruments to make sure that they were all in operating order. Since the atomic lines of neon are well-known, we took spectra of a neon discharge lamp and compared our results to the known values and then aligned our spectrometer with the data. Then we attempted another spectrograph and the results were the same: no green line. Two possible explanations of why the discharge cell did not display the same characteristics as the aurora were difference in pressure and quenching of the excited atoms

by collisions. The absolute pressures of the aurora and the discharge cell are 240 micro-torr-4.85 nano-torr and 1-10 torr, respectively. Since the difference in pressure is so great, there could be too many atoms and molecules in the discharge cell, disrupting the balance of an auroral system. However, similar experiments (Robert Young and Robert Sharpless, 1962) have revealed that the green line is obtainable in an apparatus such as ours by using only non-quenchers. This led to the conclusion that something was quenching the atomic oxygen.

“Quenching” is a term that is used to describe collisional deactivation of excited atoms. In this case, excited oxygen atoms ($O(^1S)$) collide with either O_2 or ground-state oxygen atoms. These collisions transfer energy over to the “quenchers” and leaving the atom in a less excited state such as the $O(^1D)$ or $O(^3P)$ ground state. The $O(^1S)$ atom is in a metastable state with a long lifetime of 0.7 seconds and the $O(^1D)$ has a lifetime of 170 seconds, so that the likelihood of $O(^1D)$ being quenched is even greater. To emphasize this point, the mean collision time at pressure in an aurora varies from 10 milliseconds to 30 seconds and in our discharge cell at 1 torr, the mean collision time is 8.23×10^{-5} seconds. Since the quenching rates of O_2 and O atoms are well-known, we are able to calculate the ratio of $O(^1S)$ atoms emitted versus $O(^1S)$ atoms quenched (see attached page.) The result is that only 0.14% of the $O(^1S)$ atoms emit photons, while 99.86% are quenched. This relatively low number enables us to conclude that there are not enough $O(^1S)$ atoms left to emit to be detected by the photomultiplier tube of the spectrometer. Since the signal is so weak, the atomic line is indistinguishable from the background noise on the spectral scan. Thus we are unable to see the green line.

